GPO PRICE $ ____________

CFSTI PRICE(S) $ ____________

X-641-66-52

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

NASA TM X-55456

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FACILITY FORM 602

N66 24689	
(ACCESSION NUMBER)	(THRU)
26	1
(PAGES)	(CODE)
TMX-55456	13
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FEBRUARY 1966

NASA

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT 24689

During the 4-day Gemini IV flight in June, 1965, about 100 color pictures of land areas were taken with a 70mm hand-held camera for geologic and geographic study, as part of the Synoptic Terrain Photography Experiment. This paper presents a brief summary of the objectives, methods, and results of the experiment. Representative pictures of the southwest United States, northern Mexico, and portions of Africa and the Arabian peninsula are presented and described. Preliminary study indicates that these pictures will be useful in studying regional structure, revising small-scale geologic maps, and searching for and studying impact structures.

TERRAIN PHOTOGRAPHY ON THE GEMINI IV MISSION: PRELIMINARY REPORT

Paul D. Lowman, Jr.
James A. McDivitt
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During the Gemini IV flight in June, 1965, color photographs of selected land areas were taken as part of the Synoptic Terrain Photography (S-5) Experiment (Gill and Gerathewohl, 1965). This paper presents a brief summary of the objectives, methods, and results of this photography.

The purpose of the S-5 experiment was to obtain small-scale color photographs of land areas of geological and geographical interest. Similar attempts had been made during Mercury flights MA-8 and MA-9 (Lowman, 1964), with enough success to warrant further efforts. The camera used in these and in the Gemini IV flight was a hand-held modified Hasselblad 500C with a Zeiss Planar f/2.8 lens and haze filter. On the Gemini IV mission, five magazines, each loaded with approximately 60 frames of 70mm Ektachrome MS (SO-217) film on a 2 mil Estar base, with an ASA 64 rating, were carried. In addition to the S-5 Experiment, this film was used for general purpose photography and for the Synoptic Weather Photography Experiment (S-6) (Nagler and Soules, 1965). Camera preparation, film calibration, and film processing were done by the Photographic Technology Laboratory of the Manned Spacecraft Center.

In the terrain photography experiment, coverage was requested for three major areas. First priority was given to photography of the southwestern United States because of the availability of ground control and geologic information.

Second priority was given to northeastern Africa and the Arabian peninsula because of the geologic importance of the Great Rift Valley, a major study objective of the Upper Mantle Project. Third priority was given to northern Mexico. It was stressed in pre-flight briefings that good pictures of any land area would be of value, if the planned areas could not be covered.

Two techniques were used in the terrain photography. For systematic overlapping vertical coverage along the flight path, the command pilot (McDivitt) oriented the spacecraft, using the pulse mode, while the pilot (White) took pictures at five second intervals. Because of fuel and power restrictions, this technique was used only once, during the 32d revolution. At other times, the spacecraft was in drifting flight, and pictures were taken by either astronaut whenever opportunities arose. As far as possible, pictures were taken at high depression angles, with cockpit lights out, camera axis normal to the window, and the window in shade. A residue was noticed on the windows, probably caused by flashback during second stage ignition, but had little noticeable effect on picture quality.

The experiment was highly successful. A continuous series of 39 overlapping, high depression angle pictures was taken covering northern Mexico and the southwestern United States from the Pacific Ocean to central Texas, and over 60 high-quality pictures of the other areas desired were taken. Coverage is summarized in Table 1.

Detailed study of the terrain photographs is underway by several organizations. A full discussion would be beyond the scope of this paper; instead, a few representative pictures will be presented and briefly described.

Figure 1, the first of the continuous series taken on Magazine 8, shows a portion of Baja California. It demonstrates the unique value of hyperaltitude photography by providing a synoptic view of the Agua Blanca fault, the lineament at lower left. This strike-slip fault was first described as recently as 1960 by Allen, Silver, and Stehli (1960). Stream alignments on this and the succeeding photograph suggest that it is one of a group of at least three northwest-trending faults. In addition, numerous northeast-trending lineaments are visible north of the Agua Blanca fault, possibly representing complementary shear faults. Curiously, there is little topographic evidence of the major fault east of the Sierra Juarez shown by Beal (1948) and Allen, et al (1960), although its existence has been confirmed by field mapping (C. R. Allen, personal communication). The San Miguel fault also has little visible topographic expression.

Figure 2, the third picture in the continuous 32nd revolution sequence, shows the mouth of the Colorado River, the north end of the Gulf of California, and adjacent Baja California and Sonora. Considerable geologic detail is visible, such as the lineament sub-parallel to the edge of the Sonora Desert; this is a major fault of the San Andreas system (Moody and Hill, 1956). Of equal interest, however, are the many tonal gradations (color in the original transparencies) visible in the Gulf of California. Gettys (1965) has shown that they represent variations in water depth, and points out the asymmetric sediment distribution apparent in the picture.

Figure 3, the fifth picture in the 32nd revolution sequence, shows Sierra del Pinacate and adjacent Sonora and Arizona. In the Pinacate volcanic field, most or all of the large maars and cinder cones are visible, and the extent of the field as a whole is easily delineated. In addition, considerable geologic detail in the area to the north can be identified with the aid of the Geologic Map of Yuma County (Arizona) (Wilson, 1960). Contacts between Mesozoic granites and foliated metamorphic rocks are distinct, as are the northward trending fractures in the area just north of the Pinacate field. The fact that much of the detail shown on the 1:375,000 Yuma County map can be seen on this picture, whose original scale was about 1:2,200,000, demonstrates the possibility of retaining useful resolution in extremely small-scale photographs.

Figure 4 was taken in the 32nd revolution sequence, over southern New Mexico. It demonstrates two potential geologic uses of hyperaltitude photography. The first of these, revision or compilation of regional geologic maps, is illustrated by the Sierra Carizarilla. These mountains are clearly a major volcanic field comparable to the Pinacate field in size and possibly in age (probably Pleistocene or Recent, judging from the relatively slight degree of dissection). However, the most recent maps covering this area show only scattered outcrops of Middle Cenozoic volcanics. Both the extent and assigned age appear inconsistent with the Gemini photograph.

A second potential application of hyperaltitude photography, the study of regional tectonics, is also demonstrated by Figure 4. This picture and the two adjoining ones (not shown) make it possible to see at a glance the transition zone between the folded Mesozoic rocks of northeastern Mexico (Ramirez and Acevedo, 1957) and the block-faulted volcanics of southwestern New Mexico (Dane and Bachman, 1964). The essential parallelism of fold axes in Chihuahua and fault-controlled ranges, such as the Cedar Mountains (Bromfield and Wrucke, 1961) and Dog Mountains (Zeller, 1958) in New Mexico, indicates considerable control of the faults by pre-existing folds, as proposed by Jones (1961).

Other features of geologic interest in Figure 4 are the conspicuous pediments surrounding the Florida, Cedar and Hatchet Mountains, and others. Being covered by Quaternary alluvium, these surfaces are not delineated at all on geologic maps, and are delineated on topographic maps only to the extent that they reflect topography. Hyperaltitude photographs such as Figure 4, however, provide color coverage of entire pediments without the degradation inherent in mosaics, and should be useful in studying relations between pedimentation and structure lithology, and topography.

Figure 5, taken over Mauritania during the 12th revolution, is a good example of the opportunistic photography carried out during the flight. The Richat structures were not specifically listed as subjects, although the crew had been asked to look for any large circular features which might be the roots of impact structures. The Richat structures are of considerable interest because of the reported discovery of coesite in breccia from the center of the large feature by Cailleux, et al. (1964). This picture throws no obvious light on the problem of origin, but is of value in demonstrating the ability of hyperaltitude photography to show large structures in their entirety and in relation to surrounding areas.

Figure 6 shows a portion of the Tibesti Mountains in the Republic of Chad, North Africa; the crater at left center is Emi Koussi, a recent volcano. Although not taken under optimum conditions—note, for example, the scattered light on the window and the extreme foreshortening—this picture is of considerable geologic interest. The concentric pattern in the foreground, a combination of fractures and longitudinal sand dunes, is not shown in its entirety on even the latest topographic maps of the area (the Largeau 1:1,000,000 sheet, Institut Géographic National, Paris, 1961), nor is there any known mention of it in recent geologic references (Gerard, 1958). This picture again demonstrates the usefulness of hyperaltitude photography in studying regional fracture patterns, as suggested by Lowman (1964) and Morrison and Chown (1964).

Another feature not previously mentioned in the geological literature is the circular structure below and to the right of Emi Koussi (110 kilometers S 42°W of Emi Koussi). It appears to be a series of concentric ridges, with a maximum diameter of 18 kilometers, in what Gerard (1958) shows as Upper Devonian sandstone. The nearness of the structure to the Quaternary volcanics of the Tibesti Mountains suggests an igneous origin (e.g., a laccolith) for it. However, its similarity to probable fossil impact structures such as the Clearwater Lakes (Dence, 1965) and to the Richat structures suggests that the possibility be investigated.

Figures 7, 8, and 9 are an overlapping series taken in drifting flight during the 24th revolution over Yemen and the Aden Protectorate, in the southwest part of the Arabian Peninsula. They provide an excellent synoptic view of an area which has to date been mapped only on a reconnaissance scale (see "Geologic Map of the Arabian Peninsula, 1:2,000,000; 1963; U.S. Geological Survey).

The area shown in Figure 7 is underlain chiefly by Precambrian granite gneiss (to the north) and Upper Jurassic limestones, marls, and shales, separated by a major normal fault, according to the USGS 1:2,000,000 map. The fault is expressed by what may be an erosional scarp, judging from the presumed relative resistance of the two major rock types. This picture would appear to be of great value in studying the structure of the area: in addition to the fault, which is shown on the map, several directions of jointing and faulting not shown are obvious. The alluvium/bedrock contact could also be delineated more precisely.

Figures 8 and 9 are oblique views to the southeast. In addition to the structure of Precambrian areas in the foreground (also covered by Figure 7) and top center, they show an extensive field of longitudinal dunes in the Empty Quarter. The dunes appear similar to those in the Sahara Desert classified as "complex longitudinal" dunes by Smith (1963). These photographs provide an excellent overall view of the dune field permitting, for example, study of changes in morphology as a function of distance from the crystalline highlands. The availability of color photographs, whose potential value in dune studies is cited by Smith (1963) adds to the usefulness of hyperaltitude photography of this sort.

Acknowledgments

This experiment and the interpretation of the photographs could not have been carried out without the help of many people. We are especially grateful to the following: R. D. Mercer, Manned Spacecraft Center, monitor for the S-5 and S-6 experiments; W. A. Fischer, P. B. King, L. C. Conant, and S. J. Gawarecki, U. S. Geological Survey. Personnel of the U. S. Geological Survey Library, Washington, D. C., were most helpful in literature searches. Ing. Guillermo P. Salas, Director of the Geological Institute of Mexico, provided much valuable information. K. M. Nagler and S. D. Soules, National Weather Satellite Center, principal investigators for the S-6 Synoptic Weather Photography experiment worked closely with the authors in interpretation of the photographs.

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Table 1

Film Identification	No. of Terrain Pictures*	Areas Covered	Comments
Magazine 8, Roll 3	54	Northern Mexico, southwestern United States, (continuous coverage), Florida and the Bahama Islands (intermittent coverage).	Continuous sequence of exceptional quality; intermittent pictures show considerable offshore detail.
Magazine 9, Roll 4	23	North Africa (18 pictures) Persian Gulf, southeastern United States.	North African pictures generally good; United States pictures poor.
Magazine 16, Roll 5	17	Mexico (2 pictures), Arabian peninsula and adjacent areas, Mauritania (1 picture).	Arabian pictures very good; Mauritania picture shows Richat structures.
Magazine 7, Roll 2	10	Bahama Islands (5 pictures), Arabian peninsula.	Bahama pictures show underwater topography.
Magazine 6, Roll 1	10	Northeastern Africa (7 pictures), Iraq, India, Pakistan.	Nile River and surroundings well covered.

*All pictures showing recognizable land areas are included in these figures, without regard to picture quality.

Fig. 1 Northern Baja California, Mexico. Agua Blanca fault is the lineament paralleling the spacecraft window (dark) at lower left. North at top. East-west distance at top of photograph about 80 miles.

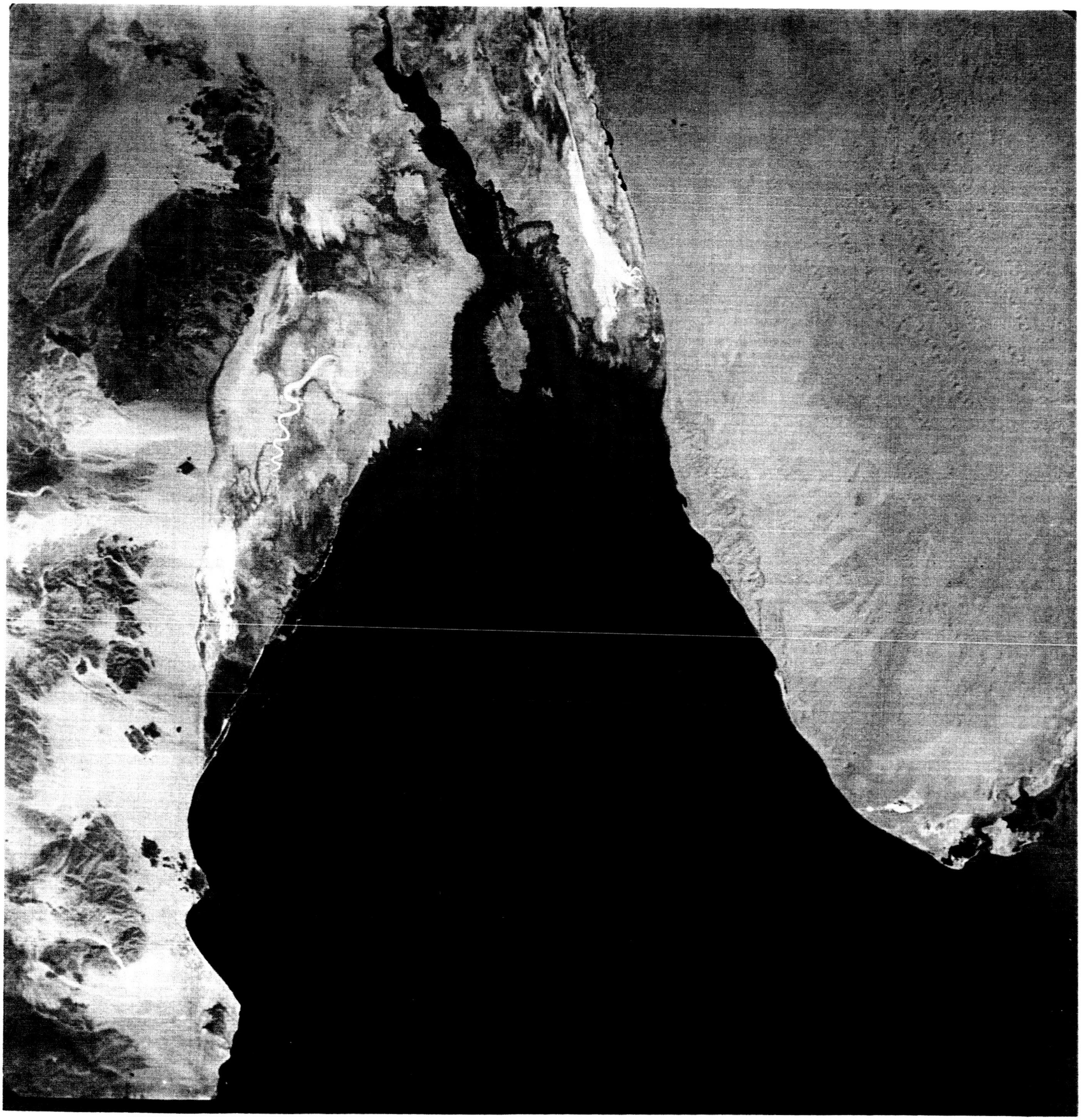

Fig. 2 Mouth of Colorado River, emptying into the Gulf of California. Sinuous feature at left is an ephemeral stream. Great Sonora Desert at right; note sand dunes.

Fig. 3 Northern Sonora, Mexico; Pinacate volcanic field (Sierra del Pinacate). Gulf of California at lower left. East-west distance at top of photograph about 80 miles.

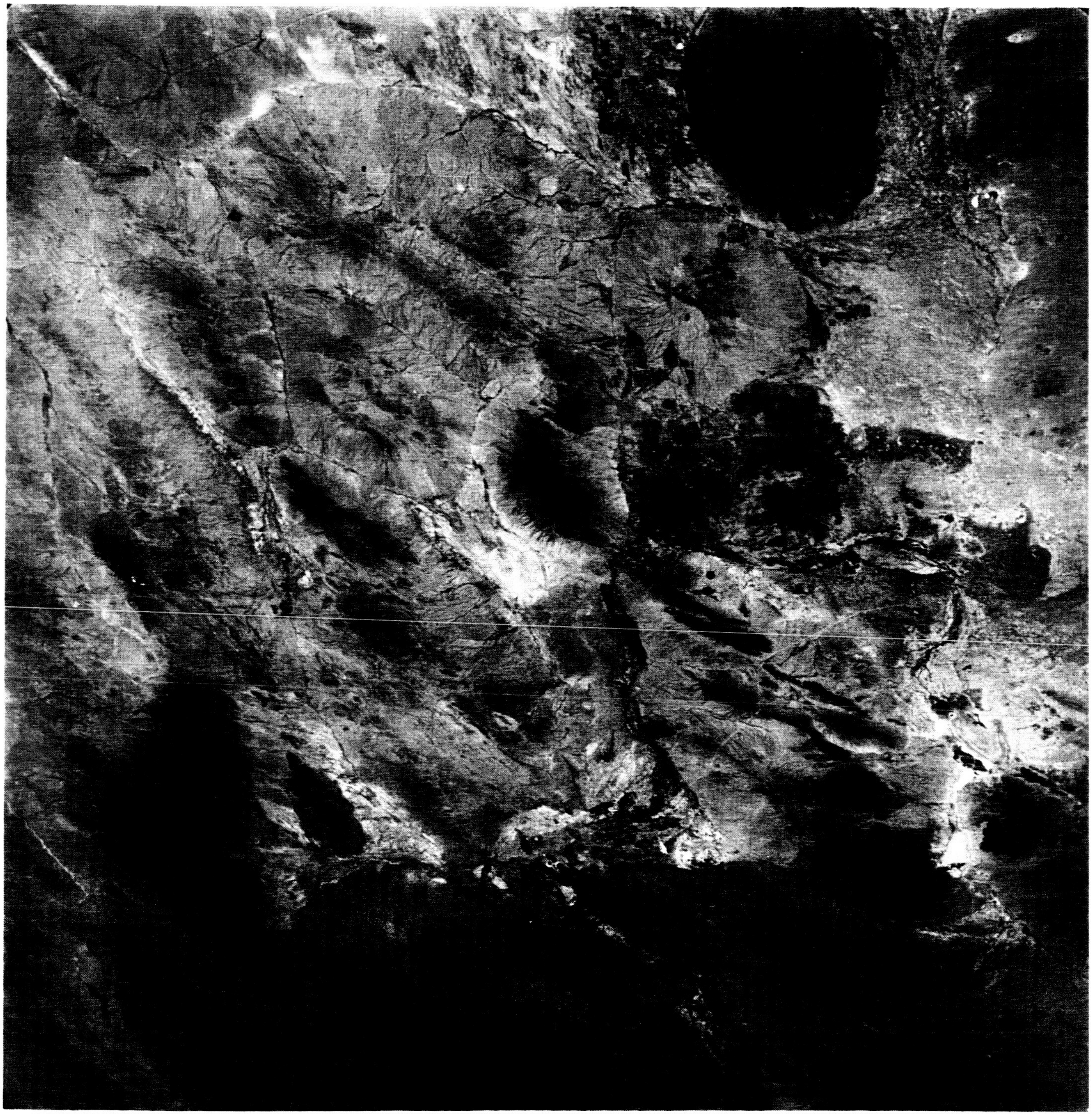

Fig. 4 Northern Chihuahua, Mexico, and southwestern New Mexico. Cedar, Hatchet, and Plorida Mountains. Sierra Carrizarilla (right center) is large volcanic field.

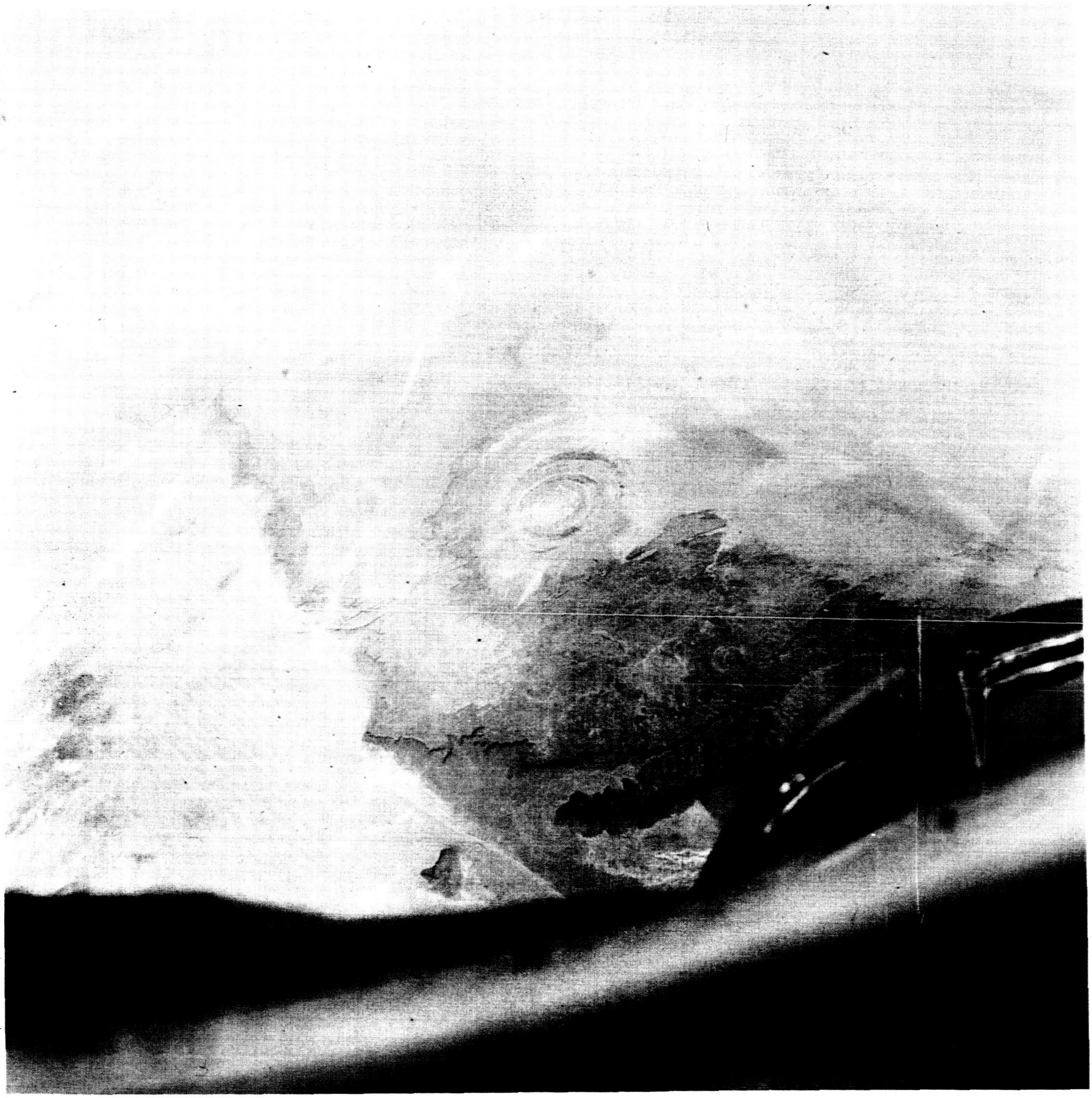

Fig. 5 Richat structures, Mauritania; north at lower left.
Smaller structure is just above and left of spacecraft nose.

Fig. 6 Tibesti Mountains, Republic of Chad; view to northwest. Prominent crater in mountains (left center) is Emi Koussi highest point in Sahara desert.

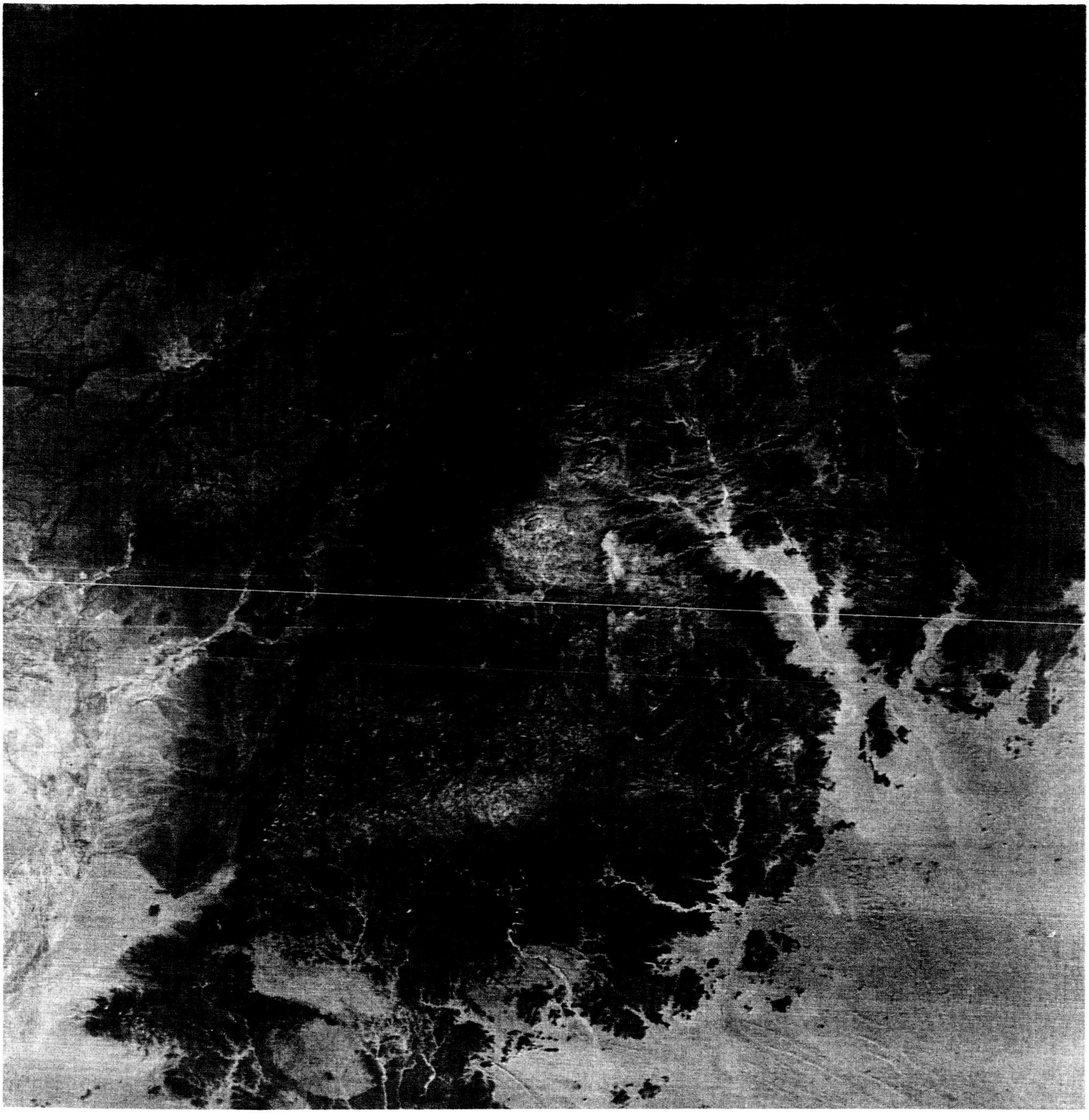

Fig. 7 Mountains in southwestern part of Arabian Peninsula; Empty Quarter at lower right. Chiefly Precambrian crystalline rocks, considerably jointed and faulted.

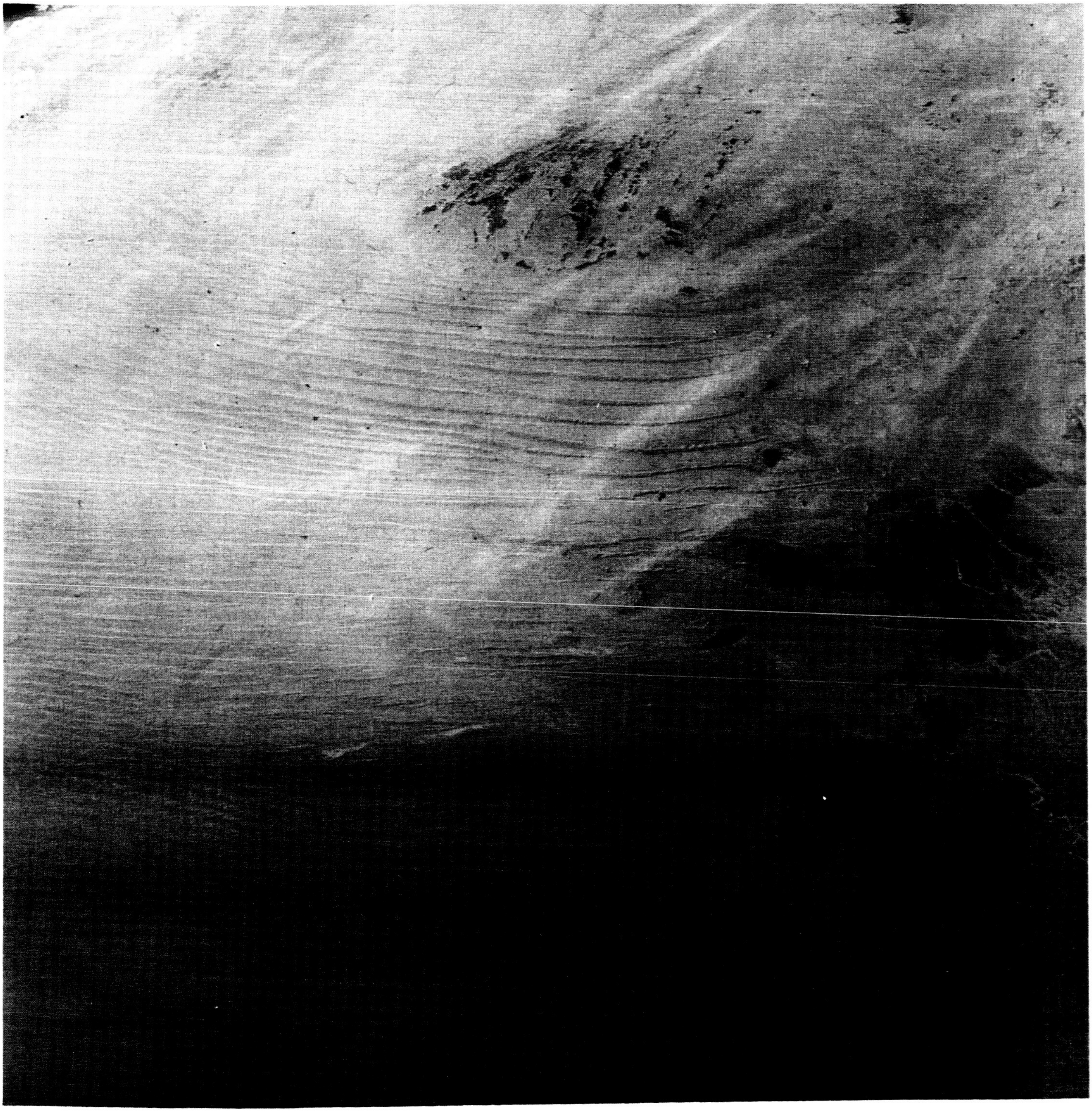

Fig. 8 Southwestern part of Arabian Peninsula, overlapping area of Fig. 7 (lower right). Seif dunes in Empty Quarter.

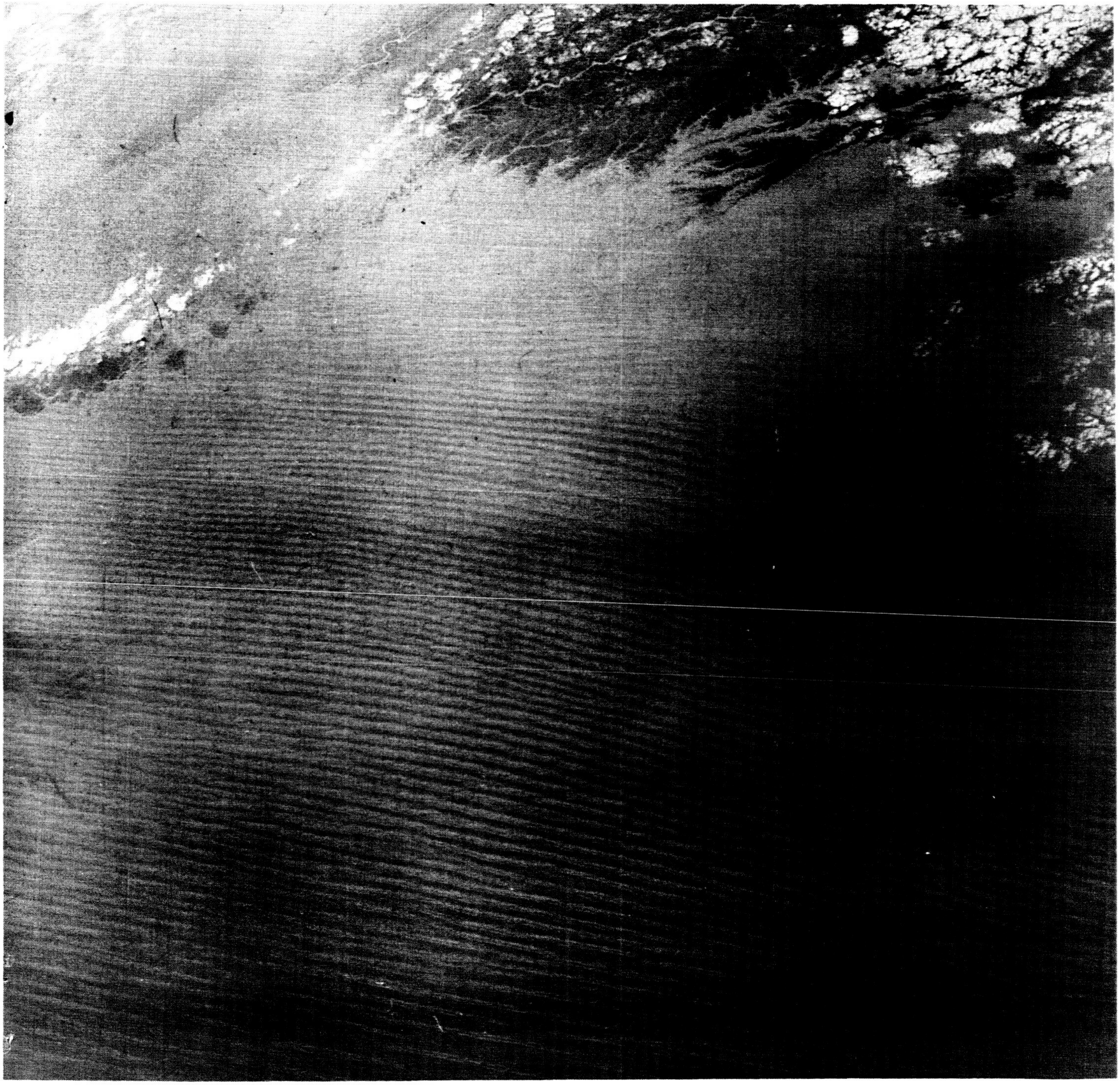

Fig. 9 Southwestern part of Arabian Peninsula, just east of Fig. 8; seif dunes in Empty Quarter. Northern edge of Hadramaut Plateau in background.